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RADIOACTIVITY INDUCED IN NaI BY TRAPPED PROTONS

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The earth satellite OSO-1 contained as one of its prime instruments the University of Minnesota γ-ray experiment, which was designed to search for extra-terrestrial γ-rays in the 50 Kev to 3 Mev range [Peterson and Howard, 1961]. The detection system consisted of an array of NaI scintillation counters arranged in various logic and shielding configurations to provide directional properties, and rejection of unwanted cosmic-ray produced background. In this letter we wish to report on radioactivity induced in the NaI crystals during the brief periods when the satellite passed through the lower edge of the inner Van Allen zone over the South Atlantic region.

The principal detector with an isotropic response was a phoswich type scintillation counter [Peterson and Nitardy, 1961] which consisted of a 5.1 cm dia x 5.4 cm long NaI crystal surrounded by a .32 cm layer of plastic phosphor. The assembly was viewed by a single photomultiplier. Energy losses greater than about 0.5 Mev in the plastic generated an anticoincidence gate, thus rejecting particle-like events. Gamma-ray like events were divided into two energy ranges; 0.3 to 1.0 Mev and 1.0 to 3.0 Mev, and were accumulated continuously in binary registers which were read out about once every 70 seconds. The counter was surrounded by about 5 gm/cm^2 of aluminum, magnesium and electronics, and was located about 18 inches from the c of g of a 450-pound payload configuration.

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The satellite was launched March 7, 1962 in a nearly circular orbit of altitude 550 km and 33° inclination. Inspection of the data revealed, not unexpectedly, that a major fraction of the rate in the isotropic channels was due to cosmic-ray produced γ-ray background except for intervals when the satellite entered the trapped radiation, when exceedingly high rates were encountered. The rates were plotted at various geographic meridia in order to obtain the latitude dependence of the cosmic-ray background, assuming a neglectable altitude effect. The results are shown in Figure 1 for a typical meridian, 60°E, which is not in a region where the satellite penetrates the inner zone. Each point on the latitude curve corresponds to different pass. The rates of each channel are clearly double-valued at this meridian. The lower values, which correspond to passes which are southbound at that meridian, result in a latitude dependence which may be interpreted in terms of cosmic ray effects; the set of values resulting from northbound passes appears anomalous. The rate vs. latitude curve for every meridian shows an effect which is qualitatively similar, but may differ in detail. In particular, the phenomena is less pronounced for meridia off the West Coast of South America.

Figure 2 shows a portion of the world map with contours of equal proton fluxes, at 670 KM, taken from the work of Freden and Paulikas [1964]. Also shown are trajectories of several typical passes. Clearly, the difference between northbound and southbound passes at 60°E meridian is that northbound passes had recently penetrated deep in the trapped radiation, while southbound passes had not. The trapped

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radiation produced an enhanced γ-ray counting rate, which apparently decays away with time.

The counting rates of the γ-ray channels as a function of time are shown in Figure 3 for two typical passes, whose trajectories are indicated in Figure 2. Deep in the trapped radiation, the rates were 10 to 100 times those encountered after leaving the region, when the rates returned to a low level. In order to determine the time history of the excess rates, other background effects must be subtracted. It will be assumed that the lower curves of Figure 2 measure the latitude effect of cosmic-ray produced γ-ray background. Lin et al. [1963], have shown that the invariant latitude Λ, obtained from the magnetic shell parameter L, gives a reasonable description of geomagnetic cutoff effects on cosmic rays. Equal values of Λ imply equal cutoffs, and it may also be assumed, equal cosmic-ray produced background. The lower curves of Figure 2, when mapped against Λ, then generate a "universal" curve which may be used for background correction on a worldwide basis. At a given orbital point, Λ is computed, the background is determined from the "universal" curve, and this is subtracted from the measured rate to obtain the excess rate.

The results of carrying out this procedure are also shown in Figure 3, for every 15° meridian where data was available. The excess rates decay in an exponential manner with time, indicating a radioactive type decay with a half-life of about 28 minutes. This procedure has been carried out for about 20 additional passes; the results are similar to those illustrated; the magnitude of the excess rate is proportional to the penetration of the satellite into the trapped region and the half-life of the decay ranges between about 20 and 30 minutes. Presumably, the variations are due to the assumptions involved in the subtraction technique.

The major mass of the instrument and the satellite is aluminum, magnesium, and steel, with traces of C, N, O, copper, lead, Si, Ge, and of course the NaI detectors. Inspection of the Nuclear Data Tables indicates only isotope related to these materials with a half-life in the 20 to 30 minute range is I^{128}. This has a half-life of 25 minutes, and is formed by neutron captures of I^{127}, the material of the detector. The decay mode of I^{128} is via β-emission, with a maximum end-point energy of 2.12 Mev. Since the range of the B particle is small, and the decay is within the crystal, the phoswich is ineffective in rejecting these events. Furthermore, the neutron capture cross section for I^{127} is rather high, being 6.3 b, 0.4 b and 0.09 b for thermal, 0.1 Mev and 1.0 Mev neutrons, respectively [Shafroth et al., 1958].

Further evidence that the postulated effect is indeed the correct one is obtained from the ratio of rates in the two energy channels. For cosmic-ray produced γ-rays, which have a power law differential spectrum with an index of about 1.8 near 1 Mev, the ratio is about 2 to 1. In the trapped radiation, assuming electron bremmstrahlung at these high energies to be neglectable, most of the event rate is due to prompt γ-rays from proton-produced nuclear reactions in the satellite mass. (Direct charged particle effects are rejected by the phoswich.) For these events, which are presumably due to γ-rays whose typical energy is about

6 Mev, the ratio is about 1.5 to 1. However, for the excess rates during the decay phase the ratio is 7 to 1, indicating a very steep energy-loss spectrum. Inspection of the decay scheme indicates most of the energy losses would be less than about 1 Mev; furthermore, other experimental evidence indicates the detector gain had drifted such that the nominal 1 Mev discriminator edge was probably at least 1.5 Mev when the data in Figures 1 and 3 were taken. Hence, the steep energy loss spectrum is consistent with the excess rates being due to radioactive decay of I^{128}.

The activity of the crystal upon leaving the trapped region was about 8×10^{-2} disintegrations/gm-sec for the passes shown. Using the thermal neutron cross-section for I^{127}, 6.3 barns, implies an equivalent dosage of 4×10^{3} thermal neutrons/cm^{2} upon the crystal, averaged over each 10-minute passage into the inner zone. Since most of the neutrons would not be thermalized, the dosage of higher energy neutrons must have been considerably greater, because the capture cross-section is less. Presumably all the neutrons were produced from proton interactions in the materials of the satellite.

Evidence from measurements on the OSO-1 satellite has been presented for the production of radioactivity in NaI by protons of the inner Van Allen zone. These protons produce neutrons in the satellite materials which are captured by the I^{127} to form I^{128}, the radioactive species observed. It would seem that any low level counting system placed on a satellite which penetrates the region of geomagnetically trapped particles has the possibility of an increased background due to similarly induced radioactivity.

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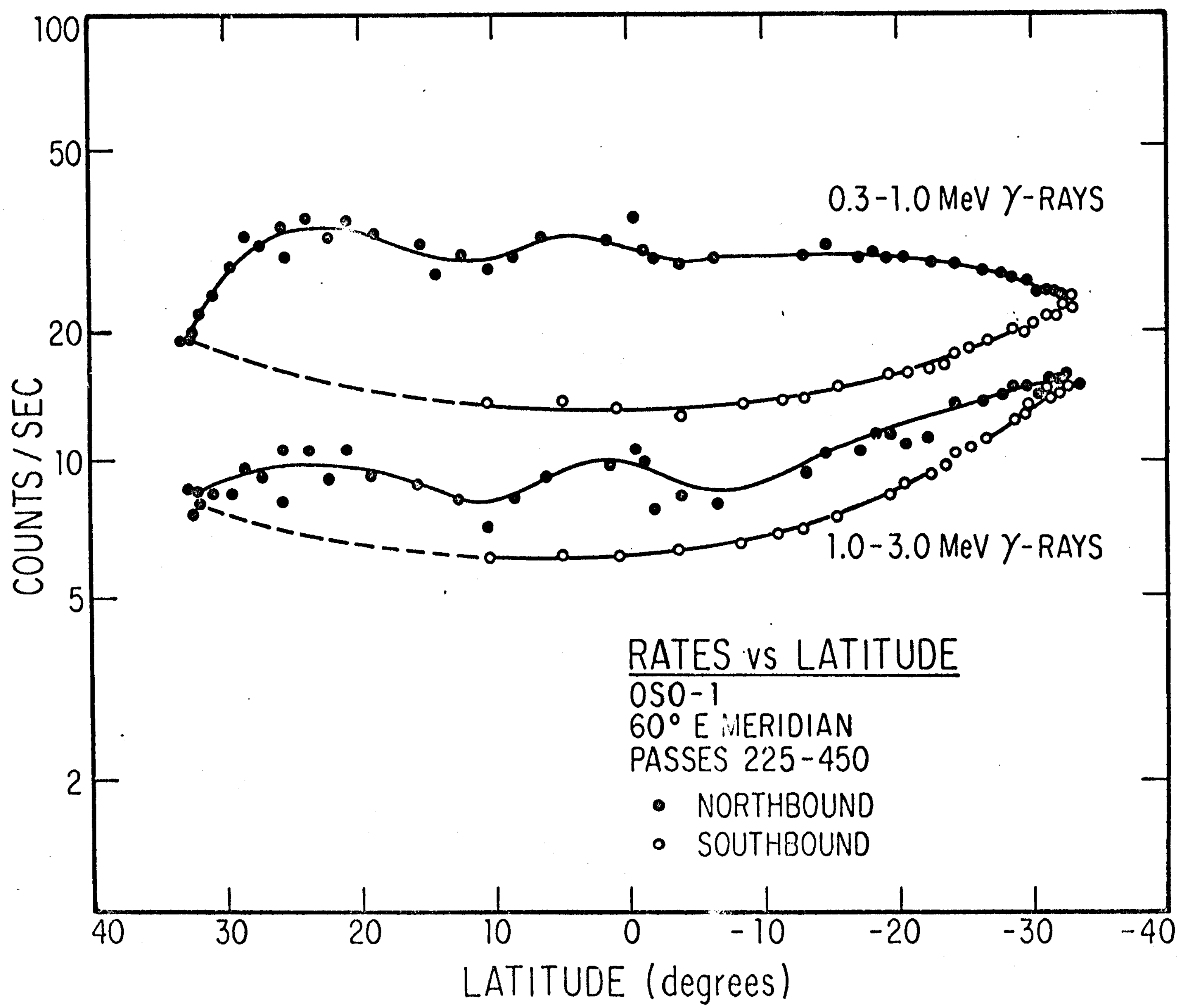
Figure Captions

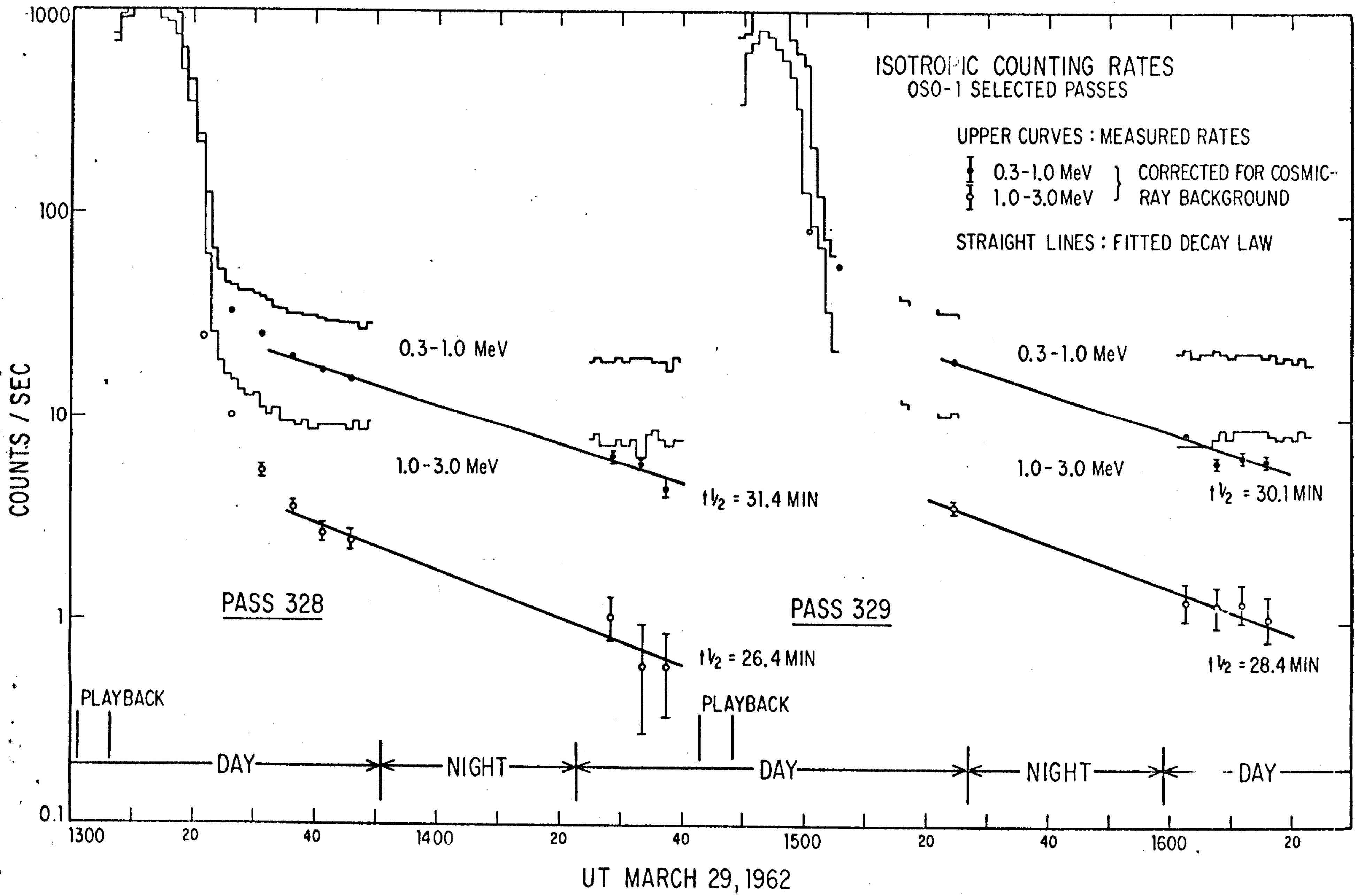
Figure 1 Counting rates vs. geographic latitude at 600 KM obtained on the OSO-1. The lower branch of the curve for each channel is presumably due to cosmic-ray produced background; the upper curve results from passes which had just passed through the trapped radiation.

Figure 2 The trajectories of a series of passes. Northbound passes at the 60°E meridian had just left the region of trapped particles; southbound passes skirted to the north of the region. Compare these trajectories with the data in Figure 1.

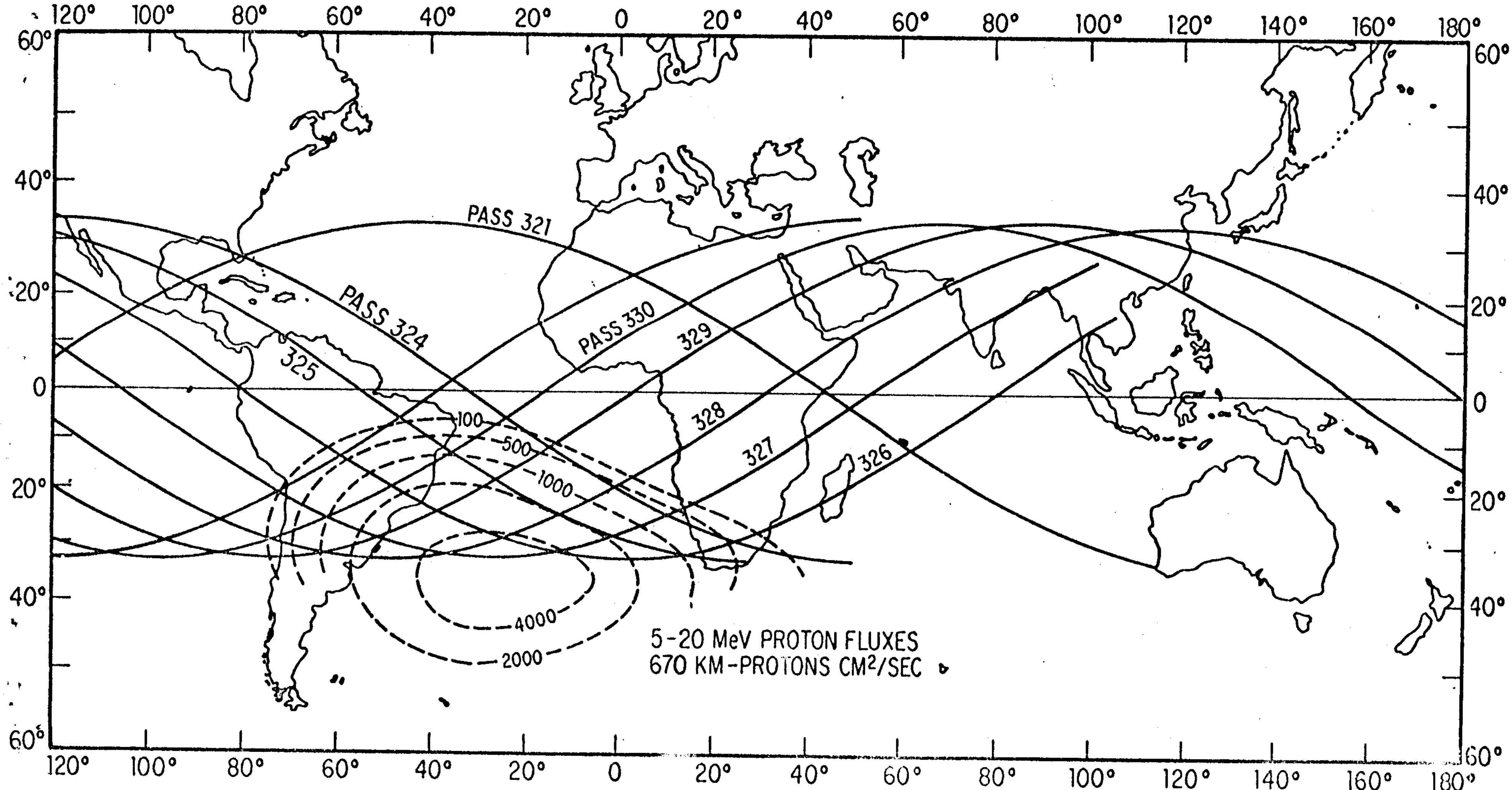
Figure 3 Rates vs. time for two of the passes indicated in Figure 2. Data is not available during satellite night, and during playback intervals. The γ-ray rates when in the trapped radiation were very high. The results of subtracting out cosmic-ray background and fitting the excess rates to radioactive decay law are also shown.



0.3-1.0 MeV γ-RAYS
1.0-3.0 MeV γ-RAYS
RATES vs LATITUDE
OSO-1
60° E MERIDIAN
PASSES 225-450
NORTHBOUND
SOUTHBOUND
COUNTS / SEC
100
50
20
10
5
2
40
30
20
10
0
-10
-20
-30
-40
LATITUDE (degrees)



ISOTROPIC COUNTING RATES
OSO-1 SELECTED PASSES
UPPER CURVES : MEASURED RATES
0.3-1.0 MeV
1.0-3.0 MeV
CORRECTED FOR COSMIC-RAY BACKGROUND
STRAIGHT LINES : FITTED DECAY LAW
COUNTS / SEC
1000
100
10
1
0.1
0.3-1.0 MeV
1.0-3.0 MeV
t½ = 31.4 MIN
t½ = 26.4 MIN
PASS 328
PASS 329
t½ = 30.1 MIN
t½ = 28.4 MIN
PLAYBACK
PLAYBACK
DAY
NIGHT
DAY
NIGHT
DAY
1300
20
40
1400
20
40
1500
20
40
1600
20
UT MARCH 29, 1962



OSO-1 TRAJECTORY
PASSES 324-331